A VLSI Processor for Fast Track Finding Based on Content Addressable Memories

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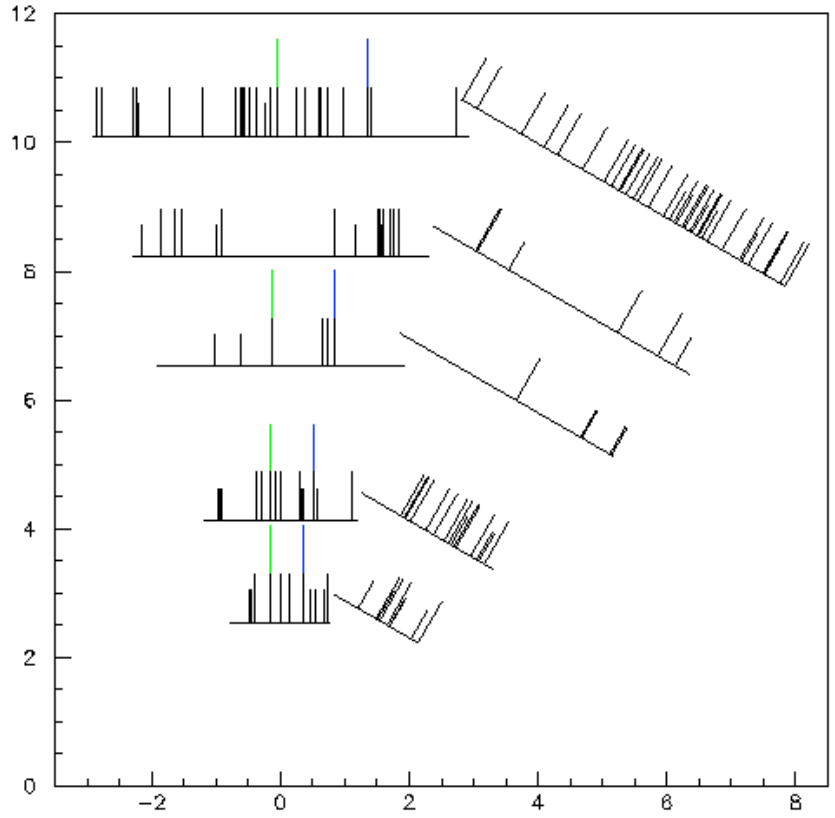
Outline

- Motivations
- Working principle
- Design
- Features & performances
- Applications
- Production & tests
- Conclusions

Hope to share this technology for other experiments

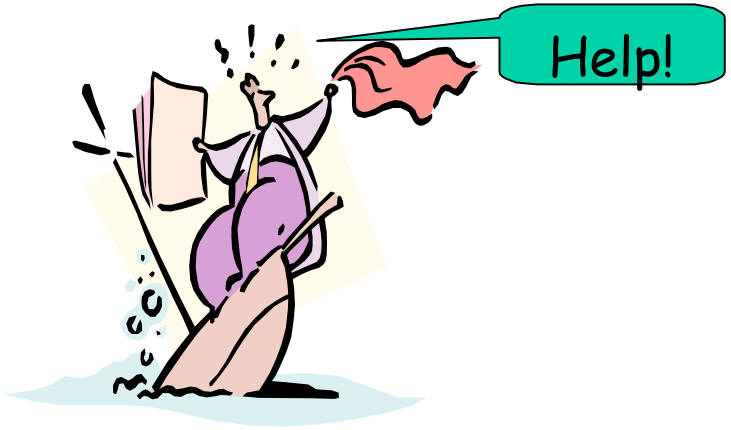
The Tracking Problem

CDF SVX: would you recognize the yellow & blue tracks without colors??

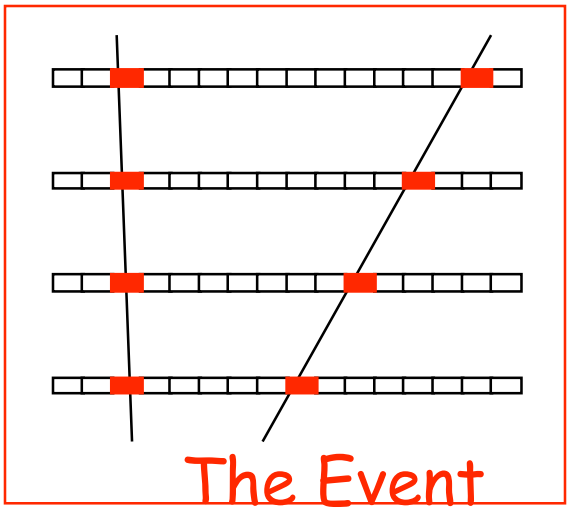


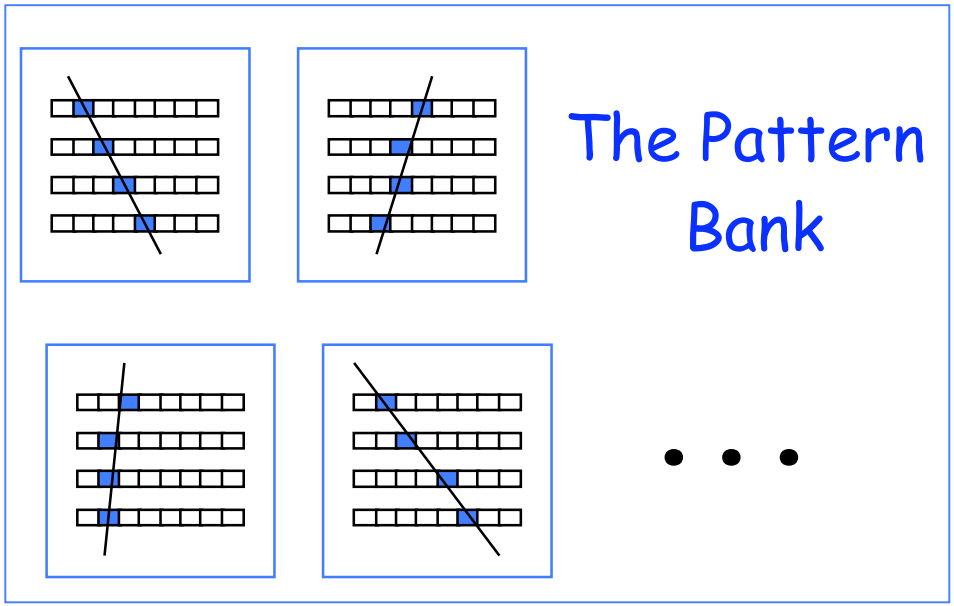
CMS 30 min. bias events + H->ZZ->4μ

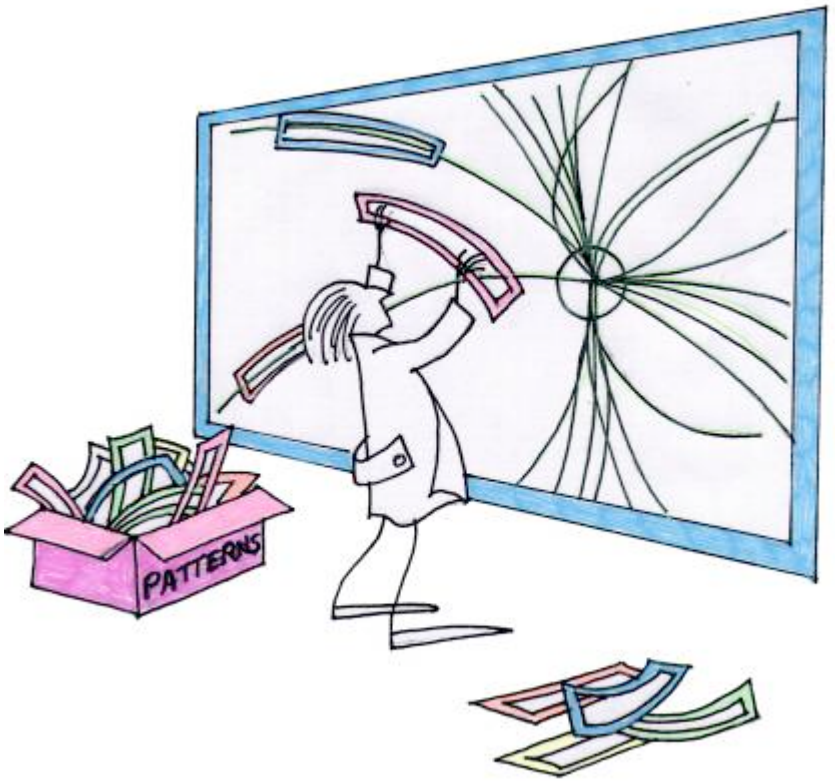
Where is the Higgs?



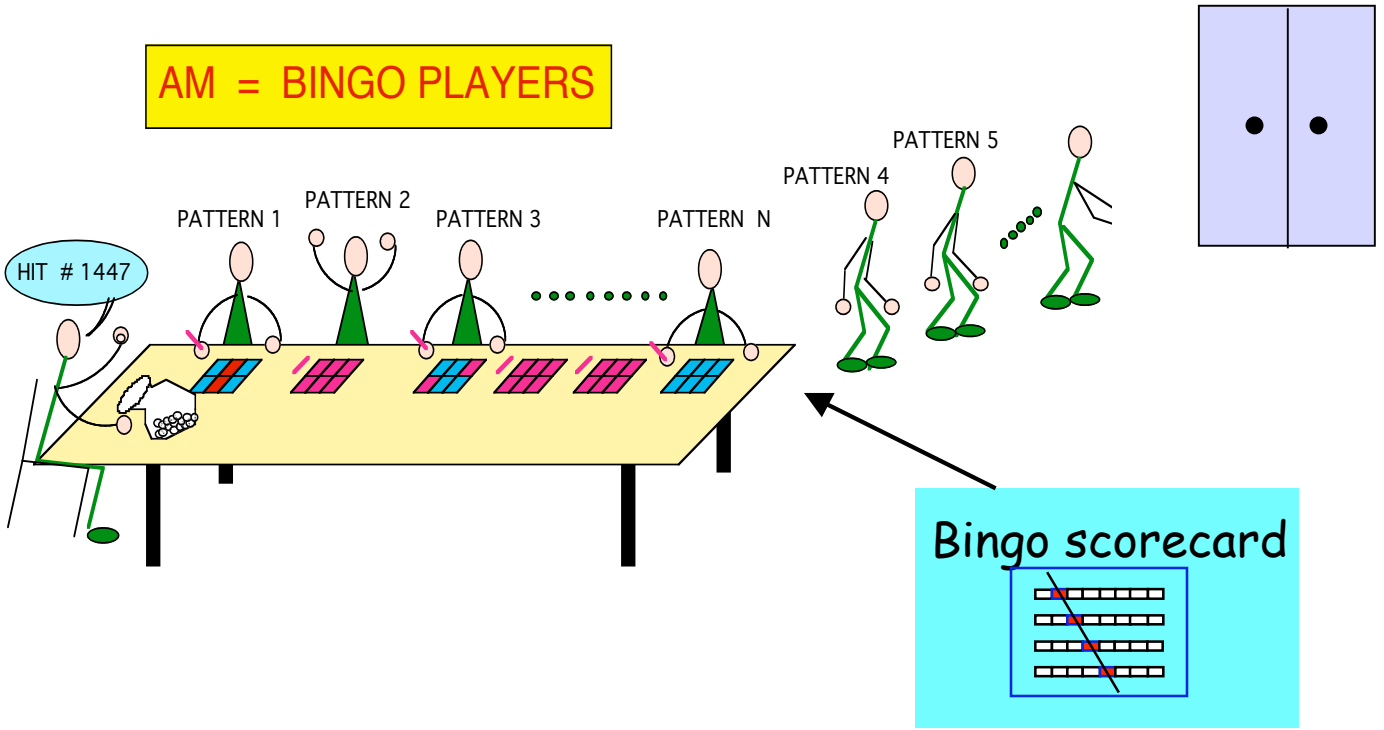
Pattern matching





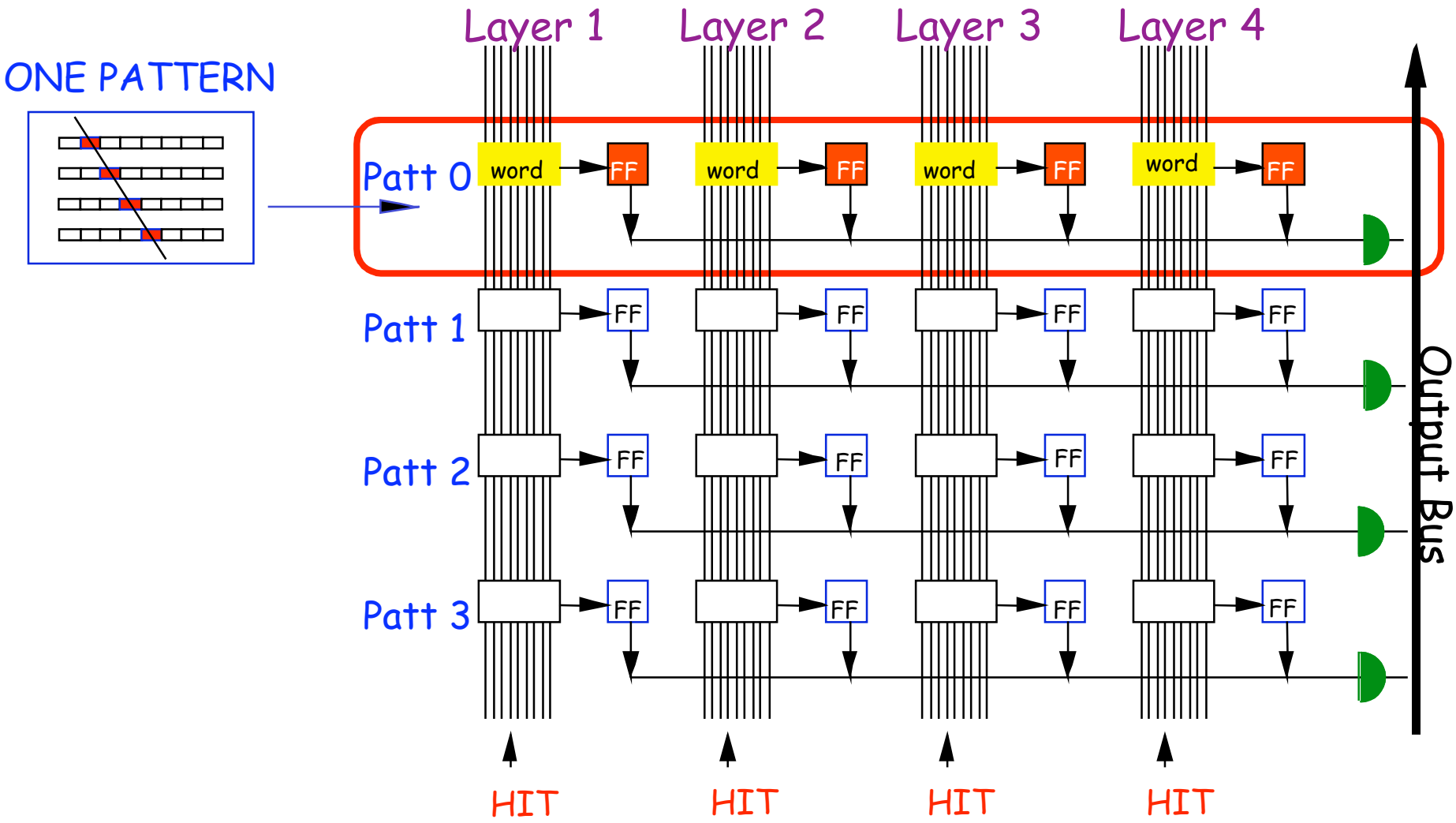


AM: Associative Memory

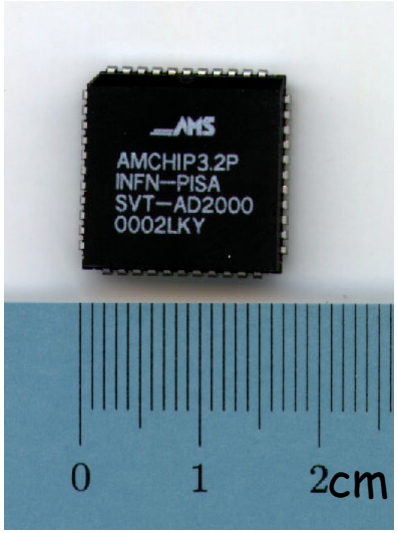


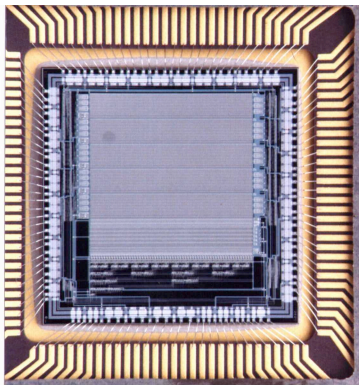
- **Dedicated device: maximum parallelism**
- **Each pattern with private comparator**
- **Track search during detector readout**

AM chip working principle



AMchip History

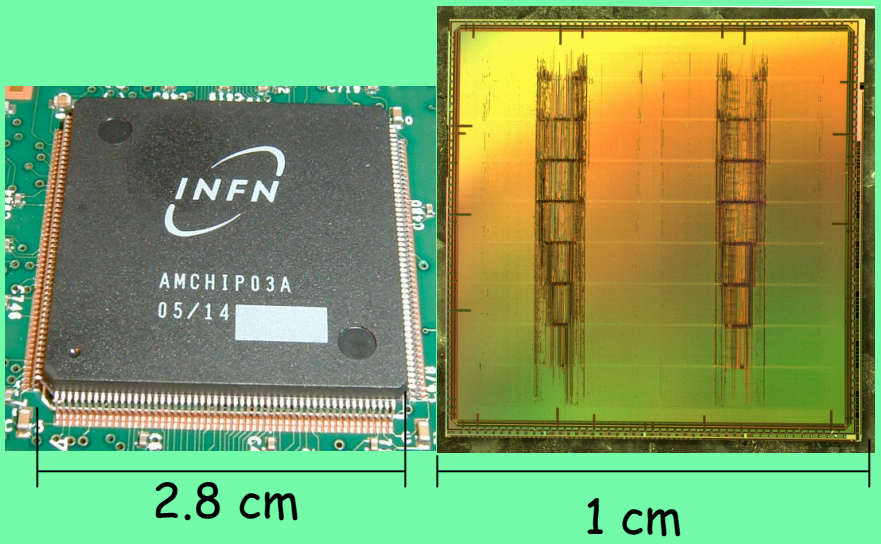




- Undoable with standard electronics (90's)

⇒ Full custom VLSI chip - 0.7μm (INFN-Pisa)

- 128 patterns, 6x12bit words each
- Working up to 40 MHz
- Single input bus



- Standard Cell design 2003-2004

⇒Chip VLSI, technology 0.18μm UMC-IMEC (INFN Ferrara, INFN Pisa)

- $1cm^2$ die size
- 5120 patterns, 6 words x 16bits each
- Tested up to 40MHz, Simulated up to 50MHz
- 6 input buses (x6 bandwidth)

AMchip03 key features

- Modular
  - Works with up to 6 detector layers (5120 patterns)
  - Or up to 12 detector layers (2560 patterns)
  - Up to 16bits per hit (65536 channels/layer: more chips --> more channels)

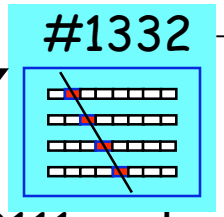
- High input Bandwidth:
  - 6 parallel input busses
  - Read input Hits at 6x40 MHz (x16bits=3.8Gbits)
  - Simulated up to 50MHz (design goal: 40MHz)

- Flexible:
  - Use array of AMchip03 for large pattern banks --> better resolution
  - Use different AMchip03 for different detector slices --> higher b/w

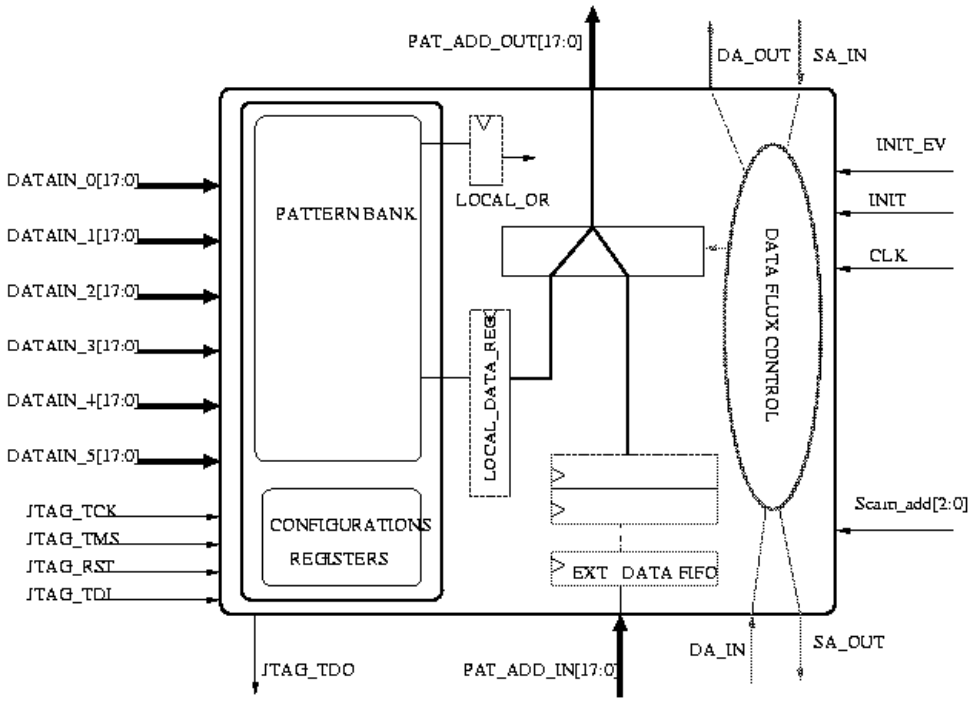
- General
  - Works for almost any detector; also mixed detectors
  - Accounts for misalignment
  - Works for inner trackers as well as muon trackers
  - Finds whole tracks, finds segments, combine segments (2D or 3D)

AMchip03 Technical features

- Output data:
  - Found pattern addresses
  - NEW!! Fired layer bitmap (e.g. 110111 --> layer3 missing)



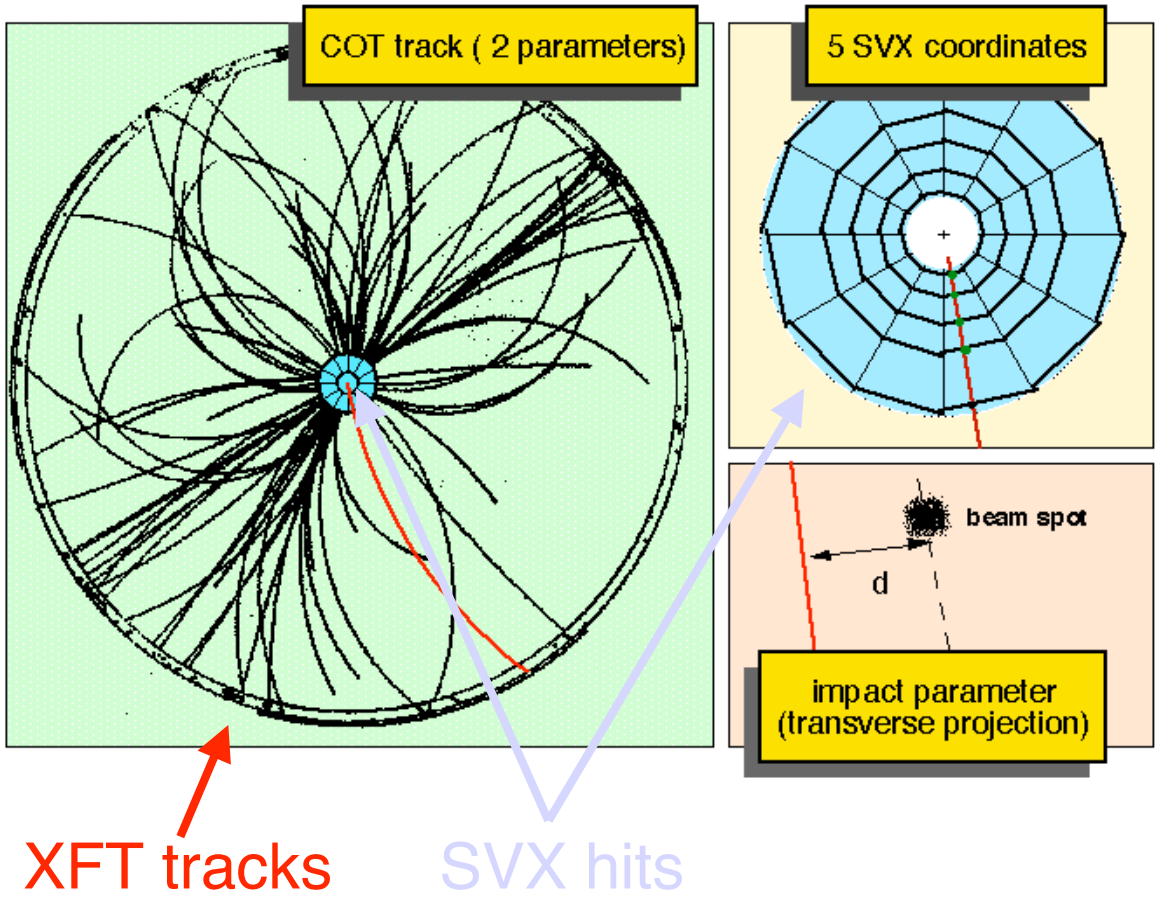
to LUT with track parameters



- IO pins: 164
- JTAG interface
  - for configuration
  - for loading patterns
- Build up MEGA pattern arrays
  - Daisy chains
  - Multiplexed
  - Mixed

- Power consumption:
  - IO (3.3V) 0.5W (uppper limit)
  - Core (1.8V) 1.2W (worst case)

AMchip03 for the SVT upgrade

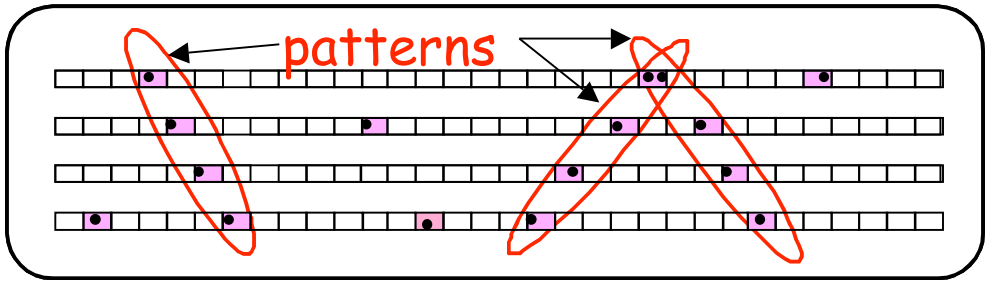


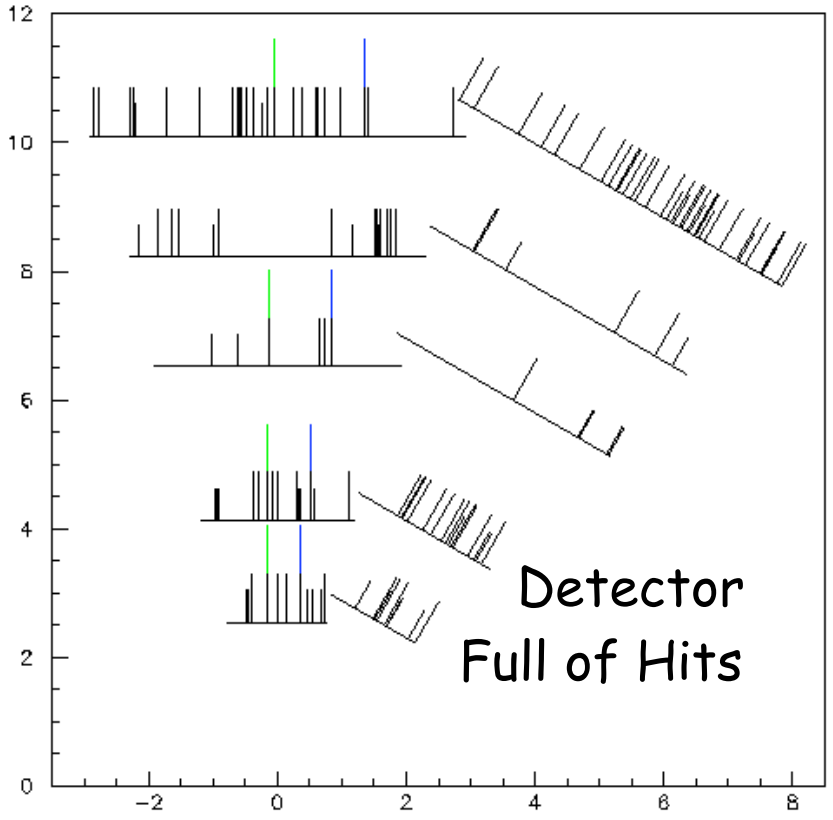
- Designed for the SVT upgrade --> part of CDF level-2 trigger
- Performs 2D pattern recognition
- Finds Tracks in the CDF Silicon detector
- Improves pattern-recognition resolution w.r.t previous AMchip

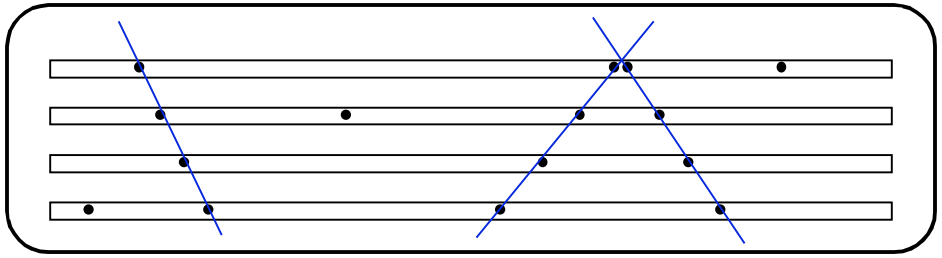
More info: N14-117 - First Step of the Silicon Vertex Tracker upgrade at CDF

AMchip03 application example

1. Find higher resolution tracks.
   Requires more patterns.
   Solve most of the pattern recognition







2. (optional) fit tracks inside roads. Thanks to 1st step it is much easier

AMchip03 future applications

- Currently used for SVT upgrade @ CDF
- Designed also for Fast-TracK R&D: whole detector LVL2 tracking @ LHC

  [IEEE Trans. Nucl. Sci. 51, 391 (2004):
  Hadron Collider Triggers with Offline-Quality Tracking at Very High Event Rates]
- Considering LVL1 applications (many ideas here):
  - @ e^+ e^- colliders
    - ☞ Could use current device
  - @ p p colliders
    - ☞ Need faster clock frequency
    - ☞ Place AMchip processor on detector itself
      - Minimize data volume: extract only candidate tracks

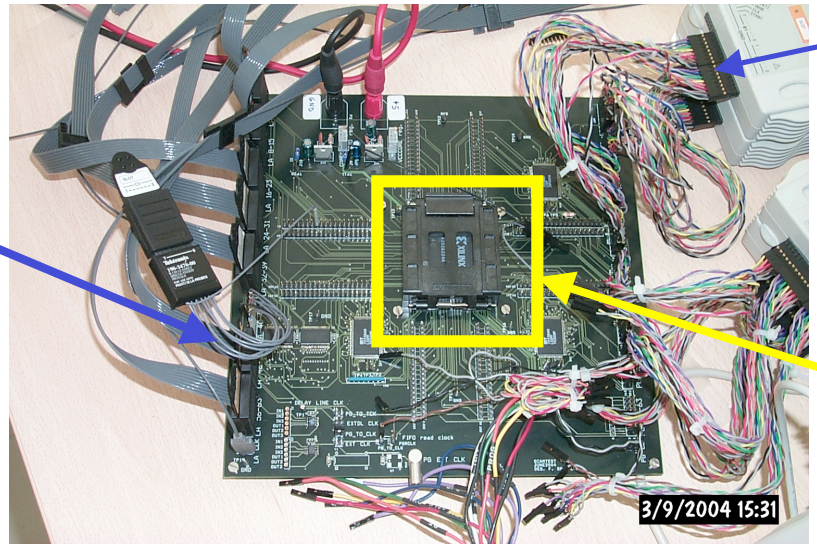
Testing AMchip03 prototypes

116 prototype chips on September 2004

MPW run – low yield 37%

Caracterization of failures: mostly single defect

Output to Logic Analyzer



Inputs from Pattern Generator

AMChip socket

3000 production chips on April 2005 good yield 70%

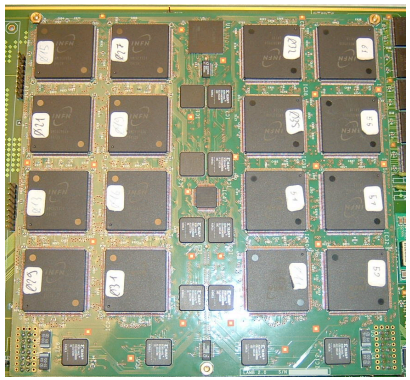
private masks → better process parameter tuning

production testing → outsourcing Microtest

AMchip03 Testing & Installation

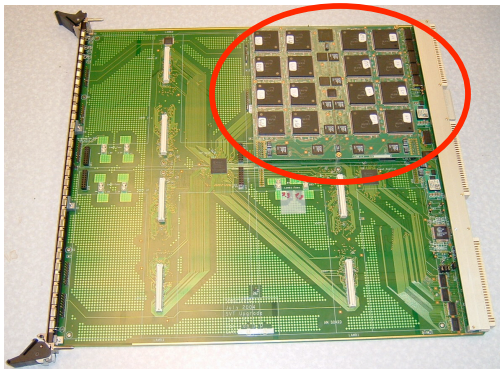
Developing the PCB with FPGAs
(2 patters instead of 5120)

Within 2 years of funding!!!

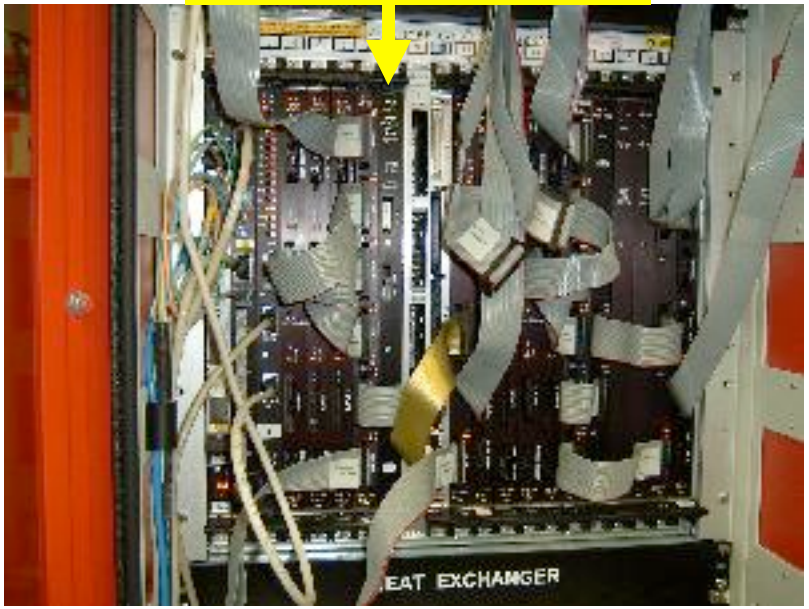


Ready for solder and test with ASIC just after prototyping.
Up to 32 chip/board (2 sides)

July 21 2005: first AMchips Installed



9U VME board
Up to 4 daughters
Up to 128 AMchip03
384 chips installed so far



Conclusions

- We have developed a 5120-pattern AMchip03 processor for the SVT upgrade
- Take advantage of latest Silicon technology
  - Write specs to installation within 2 years!!
- It is powerful, general and flexible
- We are looking forward to share this technology
  - The AMchip03 processor can be reused saving development time
  - The very same device can be applied at other experiments
  - We are considering LVL1 applications

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